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Conference Title

Implantable Neural Signal Amplifier for Epileptic Seizure Prediction

Santhanalakshmi.M[a], Alexander.J[b], Renuga.M[c], Dr.P.T.Vanathi[d]

[a]*Asst.Professor, Department of ECE,PSG College of Technology, Coimbatoe, India.*
[b] *PG Scholar, Department of ECE, PSG College of Technology, Coimbatore, India*
[c]*Asst. Professor, Department of ECE, Anjalai Ammal Mahalingam Engineering College,Kovilvenni, India.*
[d]*Associate Professor, Department of ECE,PSG College of Technology, Coimbatoe, India.*

Abstract

This paper deals with the design of low power low noise Neural signal amplifier for Epileptic Seizure Prediction. The advent of Micro-electro Arrays has driven the need for implantable electronic circuitry to detect those Extracellular neural signals(ENG). We proposed a preamplifier of fully differential LNA with g_m boosting in order to enhance the gain as well as reduce the power consumption. Low frequency high pass function has been realized with anti-parallel Diode connected PMOS. Simulation results shows that the input referred noise is 1.24uVrms from 100Hz to 5KHz, mid-band voltage gain of 44.6dB and the power consumption is 18.24uw. The results are validated using Cadence spectre simulator with 180nm technology. Inductive coupled rail-to-rail power supply circuits are discussed with a rectifier circuits. Simulation results shows that this implantable amplifier is suitable for Epileptic seizure prediction.

Keywords: Epileptic Seizure; NSA; pseudo resistor; Low frequency High Pass Function(LFHPF).

I. Introduction

Much research is being done on Epileptic seizure prediction using EEG Signals. While using EEG signals many false positives are reported. So, the better alternate for this system is to use implantable devices recording ENG signals. ENG signals are small in amplitude from 5μV to 500μV and have a low frequency spectrum of 100Hz to 5 KHz[1]. However in practice, the distance of Micro-electrode arrays (MEA) are difficult to control and the resulting ENG is very small requiring a LNA for signal amplification cum detection. The overall block diagram for Epileptic Seizure detection is shown in figure1. Output from the ENG signal acquisition amplifier(NSA) is directly taken as clinical data, further the signal is used to estimate the Short Term Maximum Lyapunov (STLmax) exponents for predicting the seizure onset[2]. The composite ENG signal consists of large DC offset due to the body where the MEA resides and Electromyography (EMG) noise, Power Line frequency

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interference. The DC offset and EMG noise can be removed by Low frequency High Pass Function [3]. MOSFET based design for low frequency bio-medical application has inherent flicker noise, it cause poor SNR. Some of the solutions to reduce the flicker noise are chopper stabilization and Auto-zeroing, both cases consumes more power, it is not advisable for implantable applications[4,5]. The flicker noise is dominating in the PMOS. The flicker noise and the valid signals are having the same 150Hz spectrum, so the transistors made large to increase its transconductance[6], thereby the noise is eliminated. The proposed LNA with sub-threshold PMOS input pair with transconductance (gm)-boosting shows valid results.

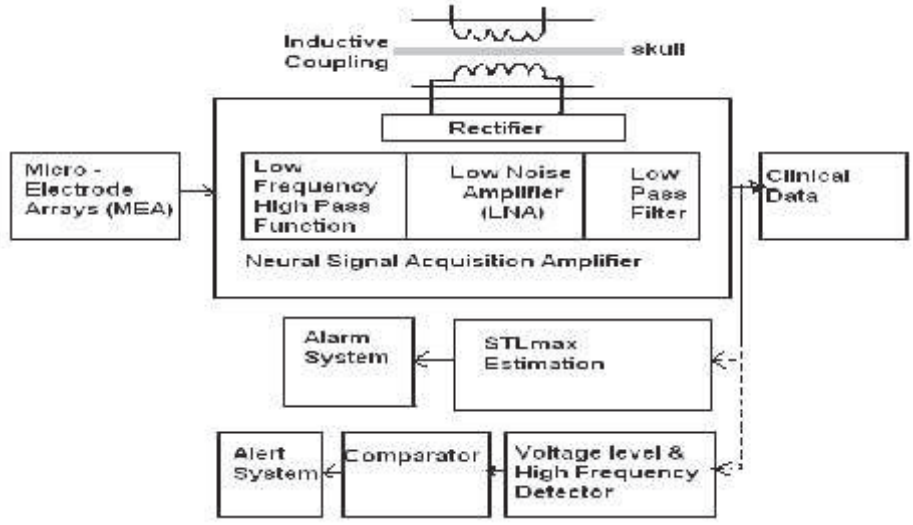

Figure 1. Overall Block Diagram of Epileptic Seizure Detection

This LNA has fully differential topology in order to eliminate the coherent noise. The design of low frequency High pass function is challenging one. In our proposed Circuit Anti-parallel Diode connected PMOS is used as Pseudo resistor. It consumes less power and exhibits bilinear characteristics. The differential output is converted into single ended by the high linear OTA-C filter, which is nothing but a Low pass Filter in this design[6]. The section1 gives brief Introduction of this Work, section II explain the inductively coupled power supply for implantable circuits, section III explains the realization of Pseudo-resistors, section IV describes the functionality of low frequency high pass function, section V explains the functional details of LNA, Section VI reveals the LNA Noise Analysis, Section VII explains about the High Linear Low Pass filter and Section VIII Concludes the work with the obtained parameters.

II Inductive coupled Rail-to-Rail Supply

For the past few years, high-performance implantable bio-medical ICs plays a major role in modern medicine. With the advent of nanotechnology, Battery based circuits are not entertained for implantable applications. Nowadays, inductively coupled link is more desirable method for patient, because of its high power transfer efficiency and safety. Bio-medical amplifiers shows good result, when using rail-to-rail power supply. In the proposed method, the sinusoidal output from the secondary coil is applied between the terminals X and Y. When potential on side X is more than that of Y, the transistors Mb,Mc,Mf and Mg are forces to shut-off while Ma,Md,Me and Mh are turned on. Therefore, we can get positively and negatively unidirected supply from terminals +Vr and –Vr respectively for both positive and negative half cycles. The unidirected supply is passed through a capacitor filter to remove its ac

contents (ripples). By using a suitable regulator we can a dc for the circuit. For the regulation, zener diode is not preferred because of its parasitic capacitance. Some CMOS circuits based on voltage reference may be used.

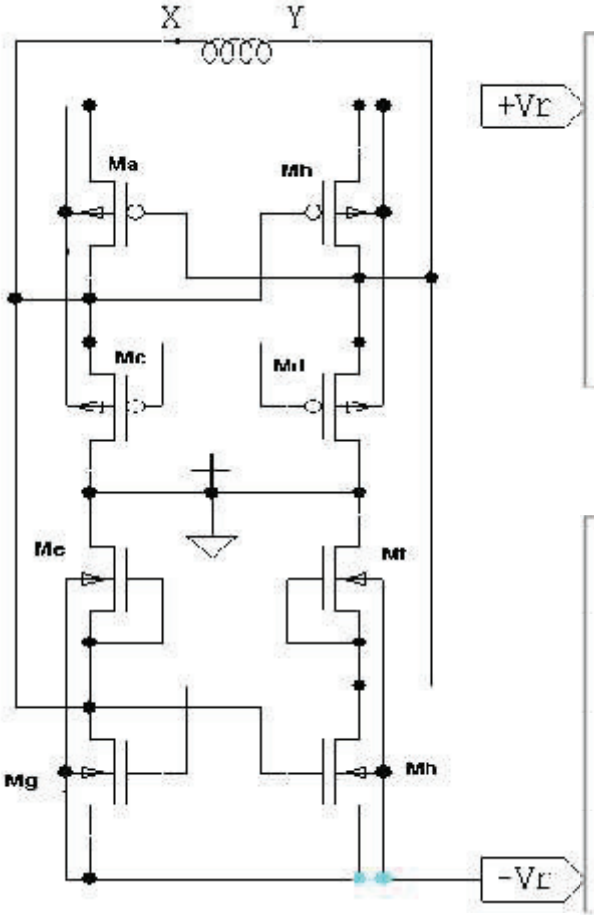

Figure 2(a) Rail-to-Rail Rectifier Circuit

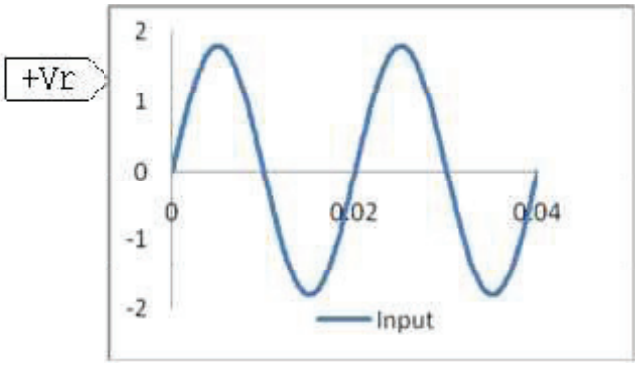

Figure 2(b) Input Waveform

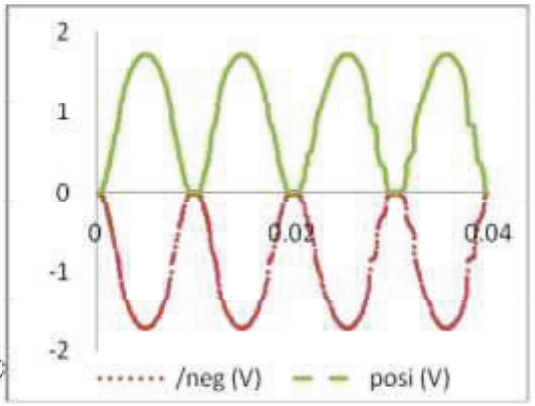

Figure 2(c) Rectifier Output Waveform

III. Pseudo-Resistors

The Pseudo-resistors plays a vital role in the realization of low frequency high pass function, in order to avoid large on-chip capacitor resulting high power consumption and poor SNR[7], The resistors of the order of several Giga- ohms are needed for this circuit. There are six different structures as shown in the figure2.The linear variation of current for each structure is plotted for comparison. The figure3. (a,b) shows the uni-linear, resulting noise disturbance is more. The transfer characteristics for single and anti-parallel connected is shown in the figure4. From this I-V curve we can understand the anti-parallel connected (DoubDio & DoubSG) pseudo resistor exhibits bilinear characteristics. The figure3.(e,f) uses sub-threshold PMOS and deep-depletion NMOS respectively. In both cases, it needs additional biasing for tuning purpose. For implantable applications, the supply is applied externally through inductive coupling. Therefore the design with large number of biasing is not preferred. Figure3. (c,d) shows

bilinear characteristics and doesn't require additional biasing for tuning purpose. Out of these two, Figure3.c is better suited for this application due to high linearity. The linear resistance curve is shown in figure5.

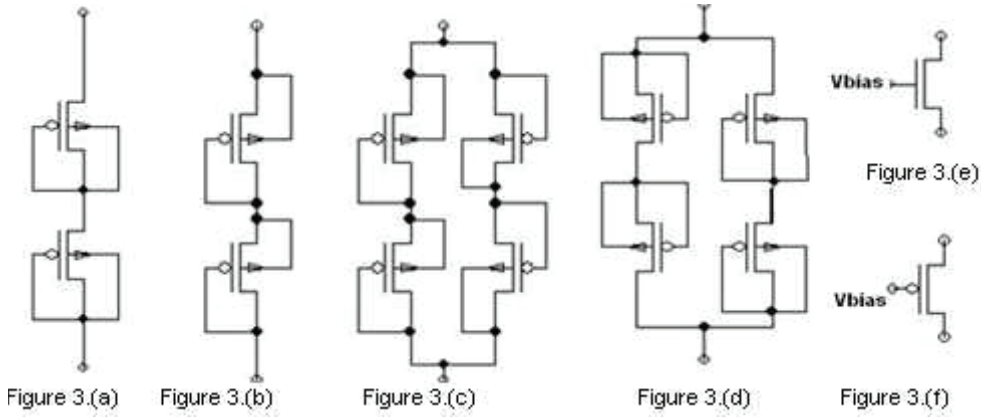

Figure 3. Different Structures of Pseudo-Resistor

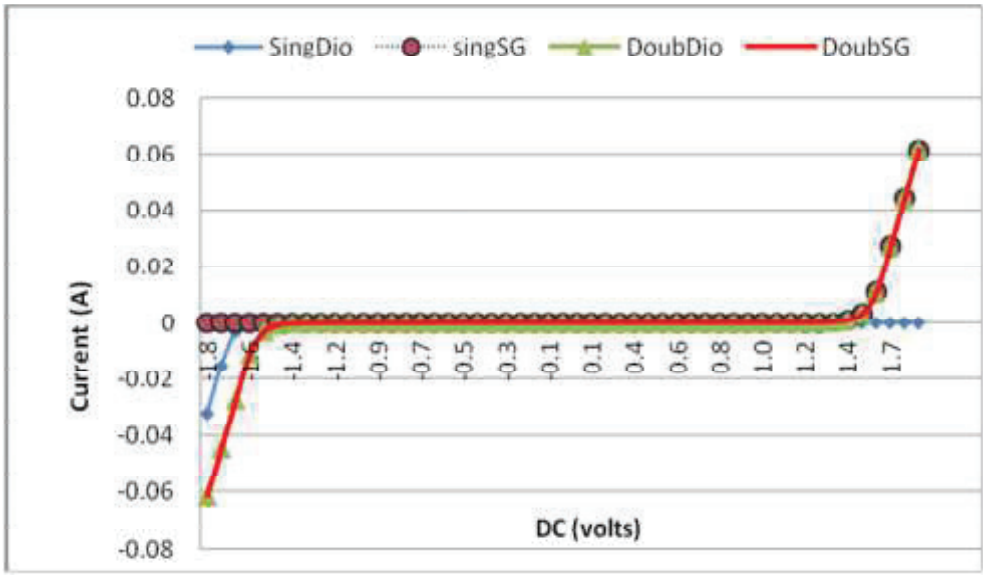

Figure4.Transfer characteristics of pseudo-resistors

The drain current of PMOS transistor operating in sub-threshold region is

$$I_d = I_o\left[1 - exp\left(\frac{V_d}{V_t}\right)\right]\exp\left[\frac{V_g - V_{th} - V_{eff}}{nV_t}\right] \quad (1)$$

Where, I_d = drain Current; V_d = source- drain voltage; V_t = thermal voltage; V_{th} = threshold voltage; n = sub-threshold swing parameter; V_g = gate-source voltage.

The differential resistance ∂R can be obtained by differentiating I_d with respect to V_d.

$$\frac{\partial I_d}{\partial V_d} = \frac{1}{R_{out}} = \frac{I_o}{V_t} \cdot \exp\left[\frac{V_g - V_{th} - V_{eff}}{nV_t}\right] \cdot exp\left(\frac{V_d}{V_t}\right) \qquad (2)$$

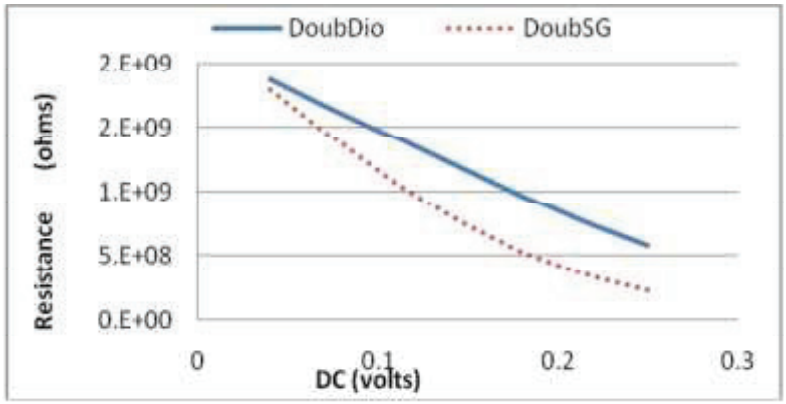

Figure5. Linearity Comparison of Anti-parallel Diode connected and Source-Gate connected.

IV. Low Frequency High Pass Function

This circuit serves two purposes. First, it avoids the DC voltage value of the body fluid where the MEAs are placed, because Dc voltage may saturate the output of LNA. Second, it removes the EMG noise spectrum which resides within 100Hz. This circuit is built by the pseudo-resistors, in order to avoid the high power consumption. The mid-band gain value is set by the capacitors C1 and C2[8]. In this application, mid band- gain is chosen by the ratio of c1 and c2 as 50. We can use either open loop or closed loop configuration as shown in figure.6.

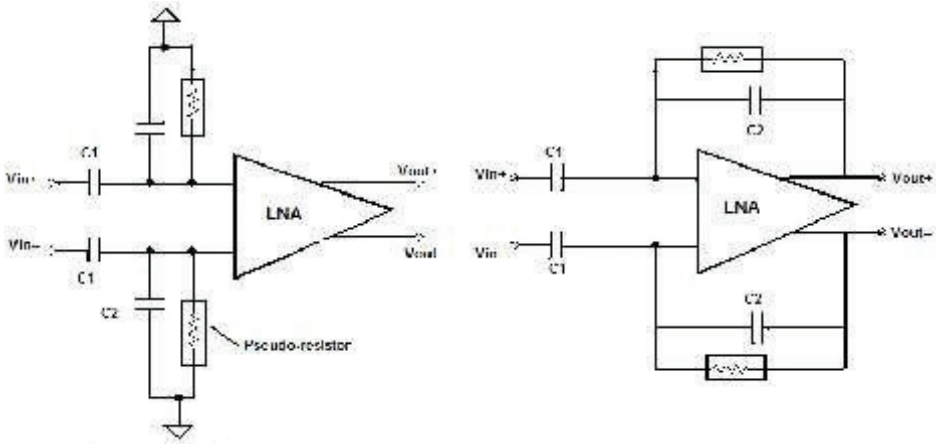

Figure6. Open Loop and Closed Loop Configuration

Simulation results in the figure6 show that the open loop configuration is better due to the high gain, Low Power consumption and stable for the region of the required Bandwidth.

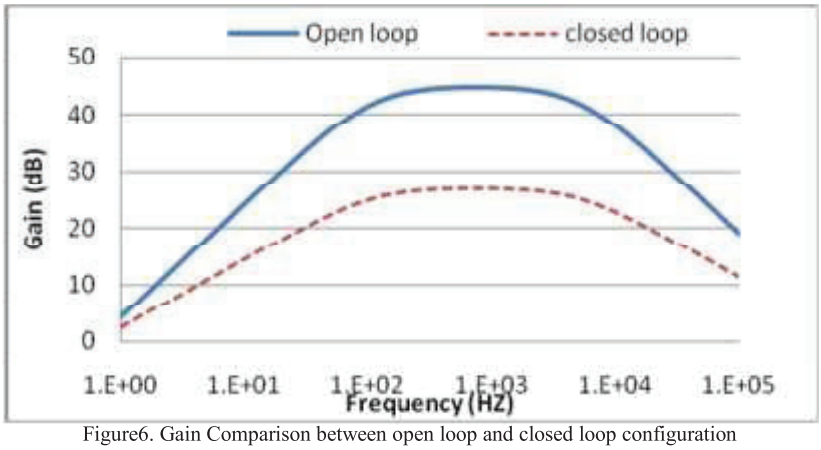

Figure6. Gain Comparison between open loop and closed loop configuration

V. *Low Noise Amplifier (LNA)*

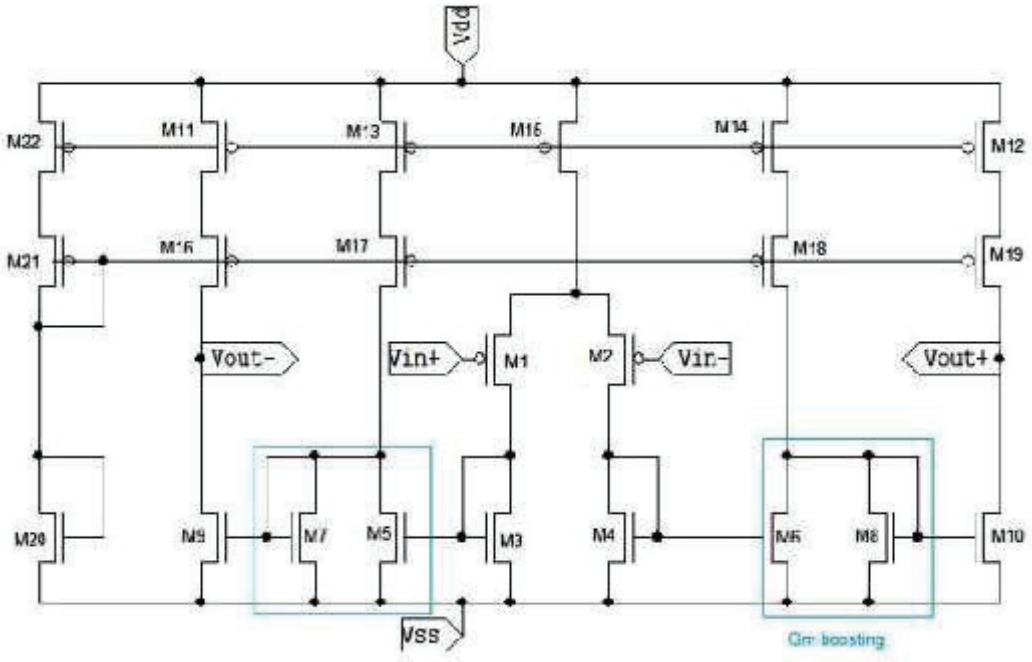

Figure.7 LNA circuit diagram

Figure7 shows the fully differential LNA circuit. Two sub-threshold PMOS input transistor pair M1 and M2 plays a vital role to reduce the flicker (1/f) noise in the circuit, because it cannot be eliminated in the succeeding stages[10]. Most of the designers prefer PMOS than NMOS; the reason behind this is NMOS gives more gain and more noise. To reduce the flicker noise, we have to choose the transconductance gm1 >> gm3 > gm5. To increase the transconductance of the input transistor, we use gm-boosting method to steer the current into the modified active load. The transconductance can be varied by changing the W/L ratio of the M5, M7. The above said condition also applicable to the negative counterpart of the amplifier. This proposed method of active load increases the gain of the amplifier with low power consumption. The transistors M20, M21and M22 provide the biasing to LNA.

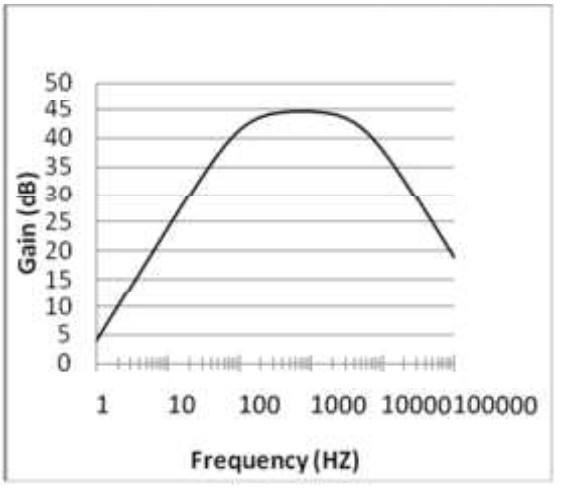

Figure8. Gain Plot of LNA amplifier

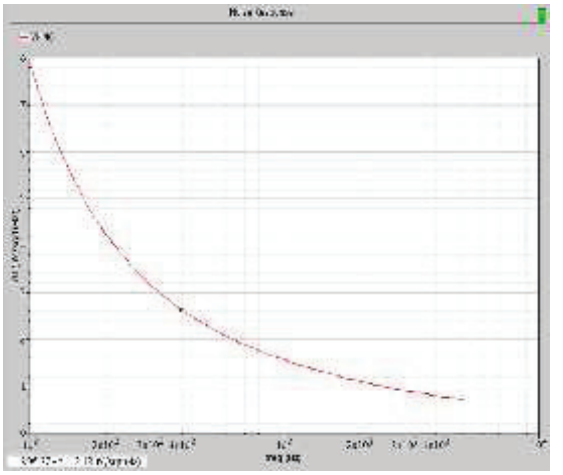

Figure9. Input referred Noise Response

VI. LNA Noise Analysis

Channel thermal noise of a MOSFET is derived from the noise current equation.

$$i_n^2 = 4.\gamma.k.T.g_m \quad (3)$$

Where, k – Boltzmann Constant; T – Absolute Temperature; g_m = transconductance.

The factor γ is a complex function of the basic transistor parameters and bias conditions. For modern CMOS processes with oxide thickness in the order of 50nm and with a lower substrate doping Nb of about $10^{15} – 10^{16}$ cm^{-3}, the factor γ is between 0.67 and 1[9].

$$v_{n,input}^2 = \frac{8kT\gamma}{g_{m1}}\left[1 + 2.\frac{g_{m11}}{g_{m1}}\frac{g_{m8}}{g_{m8}} + \frac{g_{m11}}{g_{m1}}\right] \quad (4)$$

Therefore, to reduce input-referred thermal noise, the W/L ratios of M1&M2 and the lengths of M1 & M2 are chosen to be very large, thereby maximizing the transconductance of M1 & M2, while minimizing those of M9 and M10. The input devices are the primary source of flicker noise; therefore large area PMOS transistors are used.

VII. Low Pass Filter

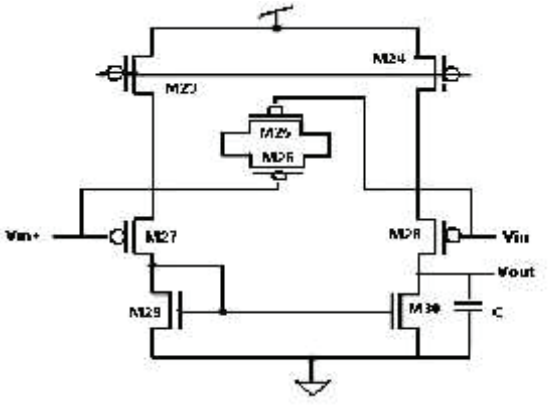

Figure10. High Linear Low Pass Filter.

High linear, OTA-C filter based simple Low pass filter is shown in the figure10. Linearity of the low pass filter is improved by source degeneration topology. In this circuit the transistors biased on triode region. M25-M26 work in a saturation-active mode for positive Vin in an active-saturation mode for negative Vin, Can result in a linear operation. The linear range is limited to $V_{in} < V_{Dsat}$ .The transconductance value for this low pass filter can be calculated from the equation given below.

$$G_m \approx \frac{g_{m27}}{1+\frac{g_{29}}{4g_{21}}} \quad (5)$$

Table1: DEVICE SIZING

Device Sizing			
Length of all transistors = 0.18μm			
Devices	**Width (μm)**	**Devices**	**Width (μm)**
M_1, M_2	10	M_{20}	0.24
M_3,M_4	2	M_{21},M_{22},M_{23}	2
M_5,M_6	8	M_{24},M_{27},M_{28}	2
M_7,M_8,M_9,M_{10}	2	M_{29},M_{30}	0.5
M_{11},M_{12},M_{13}	2	For Pseudo resistors	5
M_{14},M_{15},M_{16}	2		
M_{17},M_{18},M_{19}	2		

Table2: SIMULATED PARAMETERS

S.No.	Specification	Values
1	Over-all Gain	44.6 dB
2	LFHPF cut-off Frequency	100Hz
3	LPF Cut-off frequency	5 KHz
4	CMRR	68dB
5	Input referred Noise	1.24 V/sqrt(Hz)
6	Power Consumption	18.74 μw
7	Supply voltage	$\pm 0.8V$

VIII. Conclusion

The neural signal acquisition amplifier with 18.24uw and 1.24uVrms over the 100Hz – 5 KHz has been presented. Simulation results shows that this circuit is designed to meet all requirements for the detection and forewarning to the epilepsy affected patients for safety and clinical contexts.

Acknowledgement

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